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Elke

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(54) **INDUSTRIAL PROCESS TEMPERATURE TRANSMITTER WITH SENSOR STRESS DIAGNOSTICS**

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(58) **Field of Classification Search**

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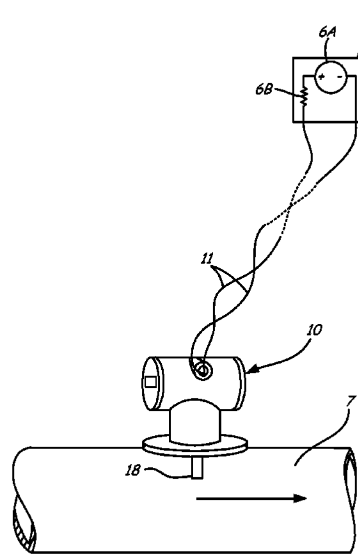
(57) **ABSTRACT**

A temperature transmitter for sensing a temperature of an industrial process includes a temperature sensor arranged to provide a sensor output related to the temperature of the industrial process. Measurement circuitry is coupled to the temperature sensor and configured to determine the temperature of the industrial process based upon the sensor output. Output circuitry provides an output related to the measured temperature. A memory is configured to store temperature information related to excessive temperature events experienced by the temperature sensor. Diagnostic circuitry diagnoses a condition of the temperature sensor or other components based upon the stored temperature information.

20 Claims, 4 Drawing Sheets



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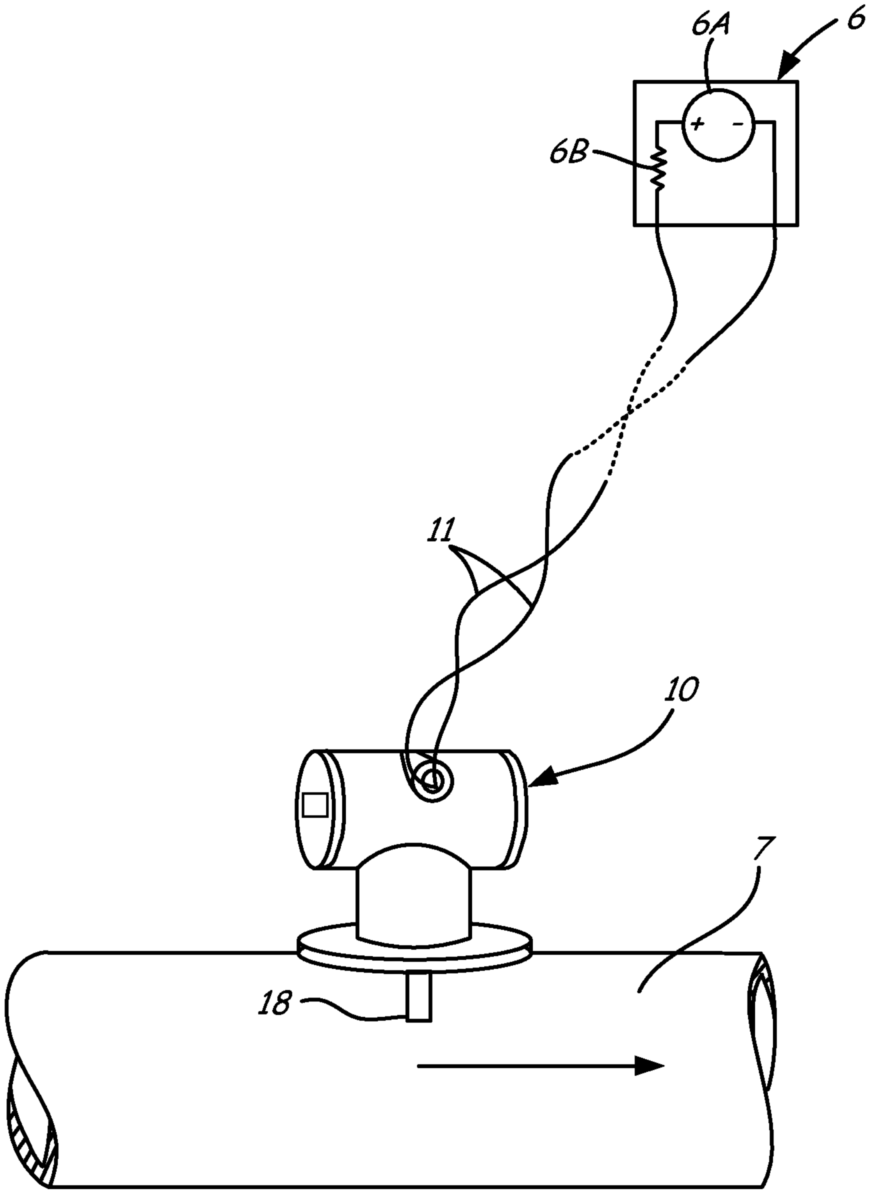
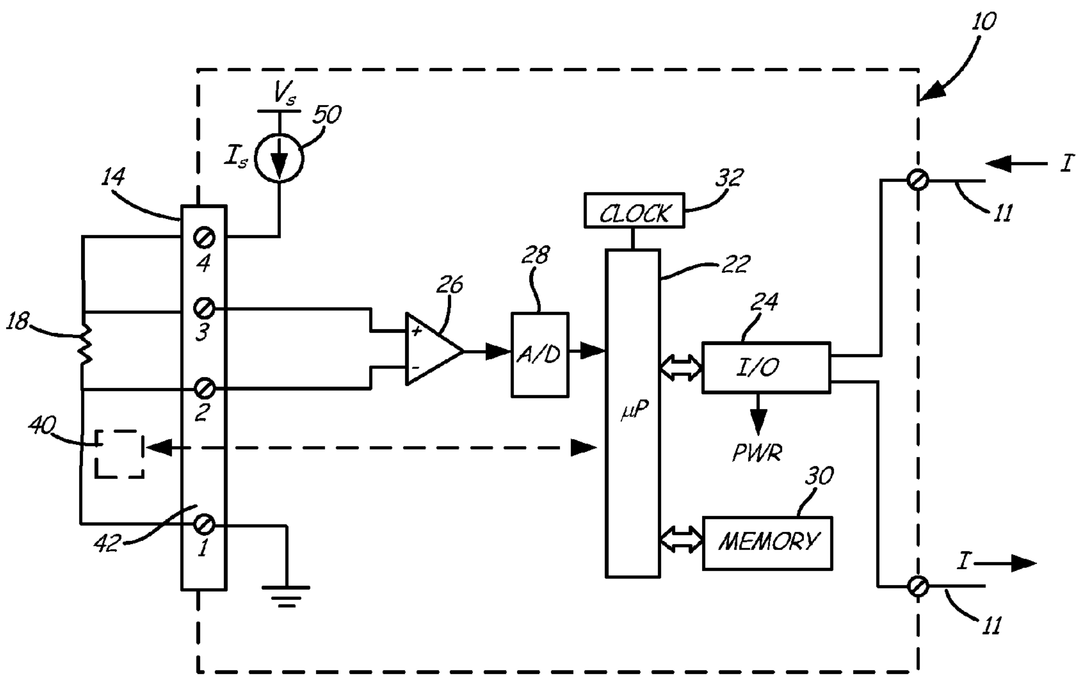


FIG. 1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V_s
50
I_s
14
32
CLOCK
I
11
22
28
26
24
18
A/D
I/O
3
2
μP
40
PWR
30
MEMORY
42
1
I
11

FIG. 2A

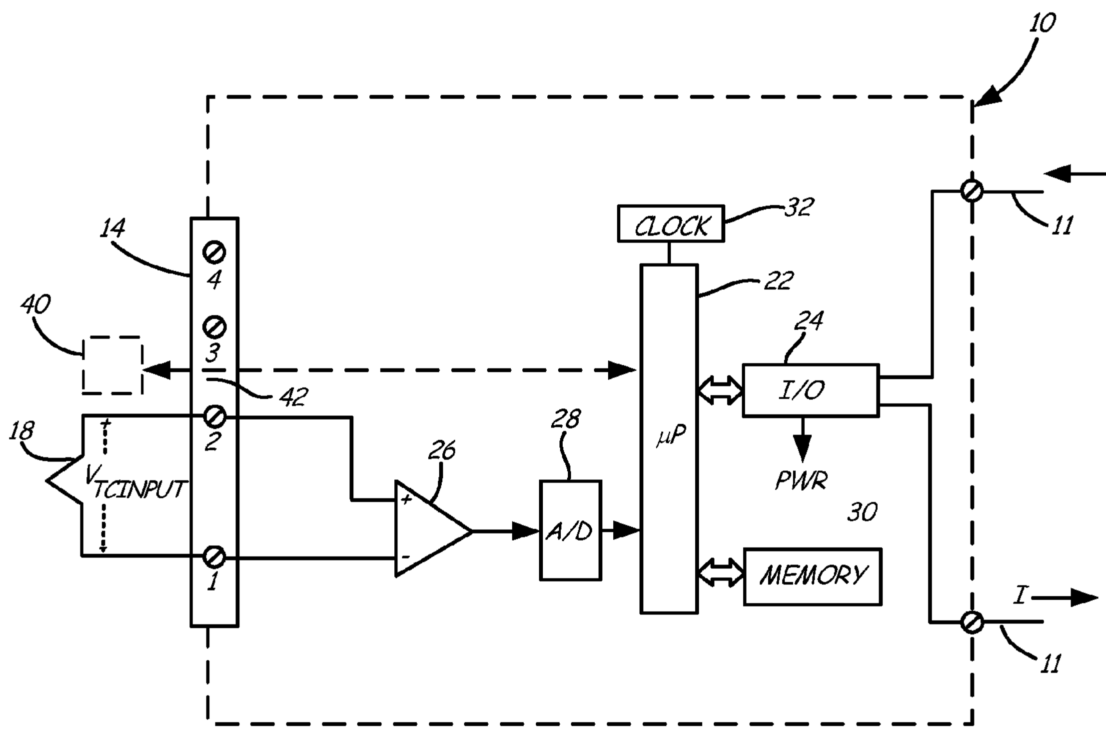
10
I
11
CLOCK
32
14
4
22
24
40
3
I/O
42
18
2
μP
26
28
PWR
$V_{TCINPUT}$
+
A/D
30
-
1
MEMORY
I
11

FIG. 2B

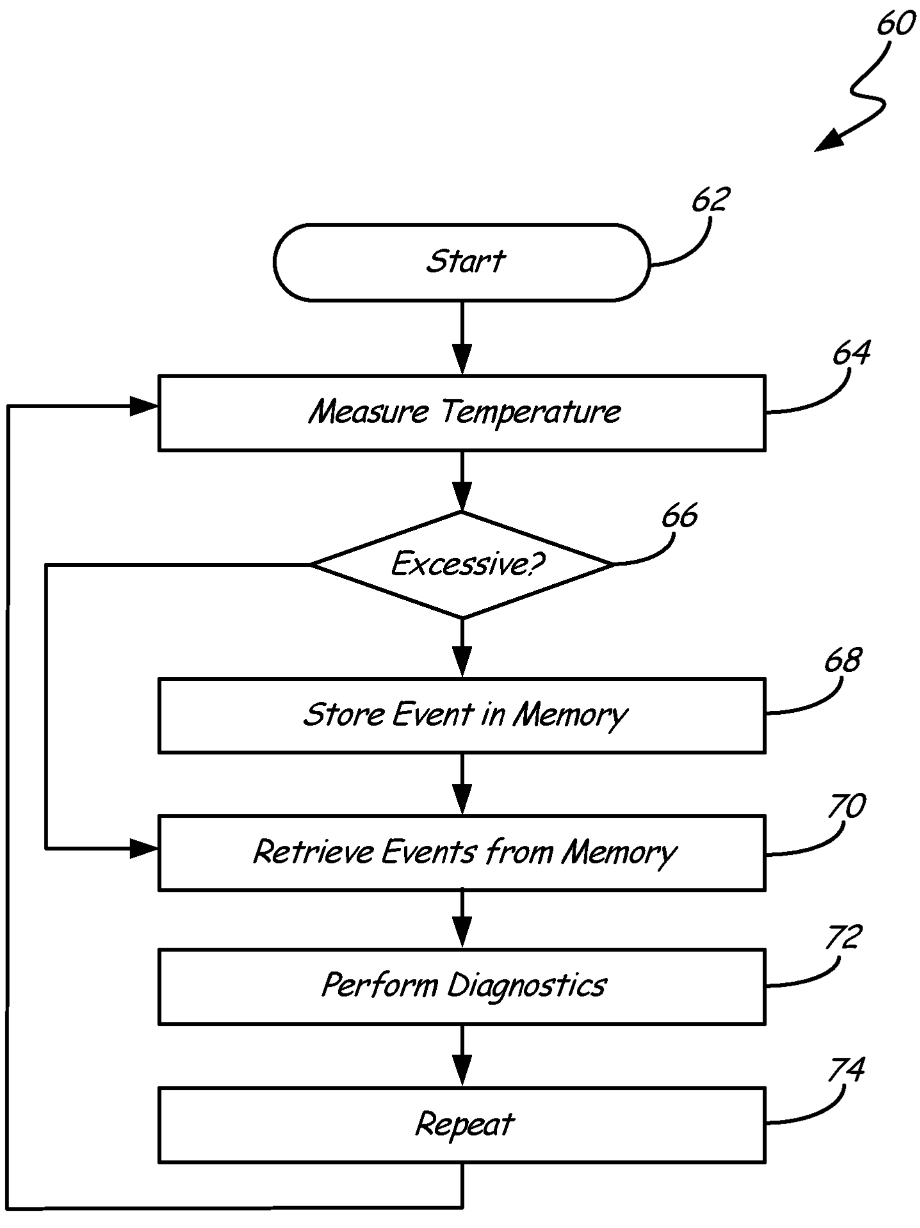
60
62
Start
64
Measure Temperature
66
Excessive?
68
Store Event in Memory
70
Retrieve Events from Memory
72
Perform Diagnostics
74
Repeat

FIG. 3

INDUSTRIAL PROCESS TEMPERATURE TRANSMITTER WITH SENSOR STRESS DIAGNOSTICS

BACKGROUND

The present invention relates to industrial process control or monitoring systems of the type used to control or monitor an industrial process. More specifically, the present invention relates to temperature transmitters which are used to sense a temperature of the industrial process.

Process variable transmitters are used to measure process parameters in a process control or monitoring system. Temperature transmitters typically include a sensor, an analog-to-digital converter for converting an output from the sensor into a digital format, a microprocessor for compensating the digitized output and an output circuit for transmitting the compensated output. Typically, this transmission is over a process control loop, such as a 4-20 mA current loop. One example parameter is temperature which can be sensed by measuring the resistance of an RTD (Resistive Temperature Device), also called a PRT (Platinum Resistance Thermometer) sensor, or a voltage output of a thermocouple sensor.

As the temperature sensor in the process variable transmitter ages, its accuracy may tend to degrade especially if the sensor experiences excessive temperatures above or below the standard temperature range of the sensor. This degradation may lead to a complete failure in which the sensor or the transmitter itself needs to be replaced. Further, the degradation may result in errors in the temperature readings. This may go unnoticed and lead to inaccuracies in the monitoring or control of the industrial process.

SUMMARY

A temperature transmitter for sensing a temperature of an industrial process includes a temperature sensor arranged to provide a sensor output related to the temperature of the industrial process. Measurement circuitry is coupled to the temperature sensor and configured to determine the temperature of the industrial process based upon the sensor output. Output circuitry provides an output related to the measured temperature. A memory is configured to store temperature information related to excessive temperature events experienced by the temperature sensor. Diagnostic circuitry diagnoses a condition of the temperature sensor or other components based upon the stored temperature information.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a simplified diagram showing an industrial process control system including a temperature sensor configured to sense a temperature of a process fluid.

FIG. **2**A is a block diagram of a temperature transmitter connected to measure temperature with an RTD sensor.

FIG. **2**B is a block diagram of a temperature transmitter connected to measure temperature with the thermocouple sensor.

FIG. **3** is a simplified block diagram of steps in accordance with the present invention.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

As discussed in the Background section, over time the temperature sensor of a temperature transmitter may age and degrade. This can lead to inaccuracies in the temperature measurements as well as an ultimate failure in the sensor. It has been discovered that one source of this degradation is due to exposure of the temperature sensor to excessive temperatures causing damage to the sensor. For example, the sensor may be exposed to a temperature that exceeds the limits of a material used to construct the sensor. The excessive temperature may be a high excessive temperature or a low excessive temperature.

The present invention monitors the number of excessive temperature events experienced by a temperature sensor in a process variable transmitter. Based upon this information, diagnostics can be performed and a determination made regarding the possibility of degradation of the sensor. The monitoring of excessive temperatures can be the number of excessive temperature events that the sensor has experienced, the duration of the excessive temperature event, and/or the temperature during the excessive temperature event. This information can be stored in a memory of the process variable transmitter or stored in a memory associated with the temperature sensor itself.

FIG. **1** is a simplified diagram of an industrial process control system **5**. In FIG. **1**, process piping **7** carries a process fluid. A process variable transmitter **10** is configured to couple to the process piping **7**. Transmitter **10** includes a temperature sensor **18** which can comprise, for example, a thermocouple or RTD sensor. Transmitter **10** is configured to transmit information to another location such a process control room **6**. The transmission can be over a process control loop, such as a two wire process control loop **11**. The process control loop can be in accordance with any desired format including, for example, a 4-20 mA process control loop, a process control loop which carries digital communications, a wireless process control loop, etc. In the example shown in FIG. **1**, the process variable is powered by a power supply **6**A at control room **6**. This power is received over the process control loop **11**. A sense resistor **6**B can be used to sense the current flowing through loop **11** and thereby monitor temperature related information sent by transmitter **10**. It is appreciated that other methods of powering the sensor and communicating the sensor information may be used.

FIG. **2**A is a block diagram of temperature transmitter **10** connected to measure temperature with an RTD sensor **18**. Transmitter **10** couples to process control loop **11** which provides power to transmitter **10** and over which information is transmitted and received. Transmitter **10** includes terminal block **14** having terminals **1** through **4** for coupling to a sensor **18** which can be, for example, an RTD temperature sensor (shown in FIG. **2**A) or a thermocouple temperature sensor (shown in FIG. **2**B). Sensor **18** can be either internal or external to transmitter **10**. Transmitter **10** includes microprocessor **22** which is coupled to control loop **11** through input/output (I/O) circuitry **24**. Circuitry **24** also powers the transmitter **10** with power from loop **11**. A current source **50** applies current I_S to sensor **18**. Positive and negative inputs of differential amplifier **26** connect to sensor **18** and provides an output to high accuracy A/D converter **28**. Memory **30** stores instructions and information for microprocessor **22**, which operates at a speed determined by clock **32**.

In operation, transmitter **10** measures the temperature of sensor **18** and transmits a representation of temperature over control loop **11**. Transmitter **10** employs the following equation to compute the resistance value of temperature of sensor **18**:

$$R_{INPUT} = \frac{V_{RINPUT}}{I_S} \quad \text{EQ. 1}$$

where:

Current source **50** provides current I_S through sensor **18** via terminals **1** and **4**. Microprocessor **22** measures the voltage drop (V_{RINPUT}) across RTD **18** between terminals **2** and **3**. In a four-wire resistance measurement such as this, the voltage drop across the connections to terminals **2** and **3** is largely eliminated, since substantially all the current flows between terminals **1** and **4**, and has little impact on the accuracy of the measurement. R_{INPUT} is converted to temperature units with a look-up table or suitable equation stored in memory **30**.

FIG. **2**B shows transmitter **10** connected to measure temperature with a thermocouple for the sensor **18** which creates a voltage $V_{TCINPUT}$ across terminals **1** and **2**. Terminals **1** and **2** couple to inputs of differential amplifier **26**. Transmitter **10** measures the temperature of thermocouple sensor **18** by determining the thermocouple voltage $V_{TCINPUT}$. This voltage is compensated as appropriate and converted into a representation of temperature based upon a lookup table, equation, or the like stored in, for example, memory **30**. Temperature information can then be transmitted on control loop **11** as described above.

In addition to memory **30** illustrated in FIGS. **2**A and **2**B, optional sensor memory **40** is also shown. Optional sensor memory **40** can be physically associated with the sensor **18** and connected to microprocessor **22** through memory connector **42** in terminal block **14**. In another example embodiment, memory **40** includes circuitry for coupling to the terminals of terminal block **14**. In either configuration, information stored in memory **40** can be read by microprocessor **22**. Similarly, microprocessor **22** can write information to memory **40**. In configurations where memory **40** communicates with microprocessor **22** through terminal block connectors **1-4**, the memory **40** can include circuitry to, for example, be responsive to a high frequency signal or a digital signal modulated onto terminals of terminal block **14**. In response to such a signal, the memory **40** can store information from microprocessor **22** or send information to microprocessor **22**.

During operation, microprocessor **22** monitors the temperature of temperature sensor **18**. If the temperature of temperature sensor **18** exceeds a threshold, information can be stored in memory **30** and/or memory **40**. As used herein, a "excessive temperature event" refers to the sensor **18** experiencing a temperature which exceeds a threshold. This threshold may be an absolute threshold, or may be a threshold based upon both temperature and duration of time. For example, if the sensed temperature exceeds a threshold value, a counter within memory **30**/**40** can be incremented. This incrementation can also be related to a duration during which the temperature is greater than the threshold. In another example embodiment, the measured temperature is subtracted from a nominal value and the result is integrated with respect to time. For example, the duration during which the sensor **18** is at higher temperature can be given a greater weight than lower temperatures. As a specific example, an occurrence of the temperature sensor **18** momentarily exceeding 500° C. can be given as much weight as the temperature sensor **18** experiencing a temperature of 200° C. for 10 hours. This can be adjusted as desired. For example, some components may fail instantaneously at high temperatures whereas some components may simply tend to degrade more rapidly when exposed to an elevated temperature which is less than a temperature which would cause immediate failure.

Based upon the information stored in memory **30**/**40** related to excessive temperature events, the microprocessor **22** can diagnose the condition of the sensor **18**. This diagnostic can be in the form of providing an output related to a predicted remaining life, an indication that he sensor **18** needs to be replaced immediately, or used to compensate for errors introduced in the temperature measurements due to the excessive temperature events. The excessive temperature information may also be used to predict errors in the temperature measurements due to excessive temperature events. Such information can be determined by characterizing a temperature sensor as it experiences excessive temperature events and storing this information in the form compensation information in memory **30** or **40**.

In some configurations, the temperature sensor **18** is removable. Optional memory **40** can be, for example, a non-volatile memory which is capable of retaining information without a separate power source. Such a configuration may be desirable because the excessive temperature event information is retained within sensor **18** itself. If the sensor **18** is removed and used with a different transmitter **10**, the excessive temperature event information will be available to the new transmitter. Further, the information can be used for failure analysis if the sensor is returned by a user because it has failed. The information stored in the memory **30** or **40** may also contain information related to when the excessive temperature events occurred, for example time and date information. In another example configuration, the particular threshold information can also be stored in the memory **30** or **40** either during manufacture, commissioning or based upon a user input. The user input may be through a local interface or received through process control loop **11**. Memory **30** or **40** may also contain other information such as other process variables, for example, vibrations experienced by the sensor **18**.

FIG. **3** is a simplified block diagram **60** showing steps in accordance with one embodiment of the present invention. The steps illustrated in FIG. **3** can be implemented using, for example, microprocessor **22** operating based upon instructions stored in memory **30**. The procedure begins at block **62** and a temperature measurement is obtained at block **64**. At block **66** a determination is made whether the sensor is experiencing an excessive temperature event. This can be by comparing the temperature to a threshold and may also factor in time in the determination of an excessive temperature event. If such event is or has occurred, excessive temperature event information is stored in memory **30** or **40** at block **68**. If there is no excessive temperature event, control is passed to block **70**. At block **70**, excessive temperature events are retrieved from memory **30** or **40**. At block **72**, diagnostics are performed based upon the retrieved excessive temperature event information. In other configurations, at block **72** other types of steps may be performed including compensation of a measured temperature value based upon the retrieved excessive temperature events. Additionally, the excessive temperature event information retrieved from memory **30** or **40** can be transmitted to another location as desired over the process control loop **11**.

Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention. As used herein, "measurement circuitry" and "diagnostic circuitry" are implemented in various components of the temperature transmitter. For example, both of the circuits can be implemented in the microprocessor **22** and may include other circuitry. For example, measurement circuitry may also include an analog to digital converter, amplifier, current source, etc. In other configurations, the circuitry may be spread among discrete elements, or may include shared elements.

What is claimed is:

1. A temperature transmitter for sensing a temperature of an industrial process, comprising:

a temperature sensor arranged to provide a sensor output related to the temperature of the industrial process;

measurement circuitry coupled to the temperature sensor configured to measure the temperature of the industrial process based upon the sensor output;

output circuitry configured to provide an output related to the measured temperature;

a memory configured to store temperature information related to excessive temperature events experienced by the temperature sensor due to heat from the industrial process; and

diagnostic circuitry configured to diagnose a condition of the temperature sensor based upon the stored excessive temperature information.

2. The temperature transmitter of claim **1** wherein the memory is located in the temperature transmitter.

3. The temperature transmitter of claim **1** wherein the memory is coupled to the temperature sensor and the temperature sensor is removable from the transmitter.

4. The temperature transmitter of claim **1** wherein the excessive temperature information includes information related to a number of times the temperature sensor has experienced an excessive temperature event.

5. The temperature transmitter of claim **1** wherein the excessive temperature information includes information related to a duration during which the temperature sensor experienced an excessive temperature.

6. The temperature transmitter of claim **1** wherein the excessive temperature information includes a temperature experienced by the temperature sensor during an excessive temperature event.

7. The temperature transmitter of claim **1** wherein the condition diagnosed by the diagnostic circuitry relates to a remaining lifetime of the temperature sensor.

8. The temperature transmitter of claim **1** wherein the diagnosed condition of the temperature sensor relates to a predicted error in the measured temperature.

9. The temperature transmitter of claim **1** wherein the measurement circuitry compensates the measured temperature based upon the diagnosed condition.

10. The temperature transmitter of claim **1** wherein the temperature sensor comprises a Resistive Temperature Device (RTD).

11. The temperature transmitter of claim **1** wherein the temperature sensor comprises a Thermocouple.

12. A method of performing diagnostics on a temperature transmitter of the type used to sense a temperature of an industrial process, comprising:

sensing the temperature of the industrial process using a temperature sensor and providing a sensor output related to the sensed temperature;

measuring the temperature of the industrial process based upon the sensor output using measurement circuitry;

providing an output related to the measured temperature;

storing excessive temperature information in a memory, the excessive temperature information related to excessive temperature events experienced by the temperature sensor due to heat from the industrial process; and

diagnosing a condition of the temperature sensor based upon the stored excessive temperature information.

13. The method of claim **12** wherein the memory is located in the temperature transmitter.

14. The method of claim **12** wherein the memory is coupled to the temperature sensor and the temperature sensor is removable from the temperature transmitter.

15. The method of claim **12** wherein the excessive temperature information includes information related to a number of times the temperature sensor has experienced an excessive temperature event.

16. The method of claim **12** wherein the excessive temperature information includes information related to a duration during which the temperature sensor experienced an excessive temperature.

17. The method of claim **12** wherein the excessive temperature information includes the temperature experienced by the temperature sensor during an excessive temperature event.

18. The method of claim **12** wherein the diagnosed condition of the temperature sensor relates to a remaining lifetime of the temperature sensor.

19. The method of claim **12** wherein the diagnosed condition of the temperature sensor relates to a predicted error in the measured temperature.

20. The method of claim **12** including compensating the measured temperature based upon the diagnosed condition.

* * * * *